

WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services



**World
Meteorological
Organization**

Weather · Climate · Water

WMO-No. 1150

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2015

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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at http://www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html. Acronyms may also be found at http://www.wmo.int/pages/themes/acronyms/index_en.html.

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EXECUTIVE SUMMARY

Each year the impacts of severe hydrometeorological events around the Earth give rise to multiple casualties and significant damage to property and infrastructure, with adverse economic consequences for communities that can persist for many years. All this happens in spite of the fact that many of these severe events have been well forecast, with accurate warning information disseminated in a timely fashion by the responsible National Meteorological and Hydrological Service (NMHS).

The reasons for this apparent disconnect lie in the gap between forecasts and warnings of hydrometeorological events and an understanding of their potential impacts, both by the authorities responsible for civil protection/emergency management and by the population at large. Put simply, while there is a realization of what the weather might be, there is frequently a lack of understanding of what the weather might do.

If this gap is to be closed, then an all-encompassing approach to observing, modelling and predicting severe hydrometeorological events, and the consequent cascade of hazards through to impacts, needs to be developed. Tackling this problem will require a multidisciplinary and highly integrated and focused endeavour. This is essential to ensure access to the best possible science, and the optimum services, to manage multi-hazard events today, and to provide the best possible evidence base on which to make the costly decisions on infrastructure needed to protect the population in the future as climate changes.

Improving the understanding of the potential impacts of severe hydrometeorological events poses a challenge to NMHSs and their partner agencies, particularly disaster reduction and civil protection agencies (DRCPAs). These Guidelines establish a road map that identifies the various milestones from weather forecasts and warnings to multi-hazard impact-based forecast and warning services.

For completeness, these Guidelines also describe the ultimate step of forecasting actual impacts, although it is recognized that this is a highly sophisticated exercise, requiring strong collaboration with partner agencies and significant research into exposure and vulnerability. For many WMO Members this step will not be the responsibility of the NMHS but rather that of the relevant DRCPA and other partners.

Progressing from weather forecasts and warnings to multi-hazard impact-based forecast and warning services represents a paradigm shift in service delivery for many NMHSs, but one which is entirely consonant with the Implementation Plan for the WMO Strategy for Service Delivery adopted in 2013. To assist Members with this process, the Guidelines include many examples that help to illustrate the nature of the changes described and a section on a possible approach to change management of relevance in this context

CHAPTER 1. THE CASE FOR IMPACT-BASED FORECASTING

It is no longer enough to provide a good weather forecast or warning – people are now demanding information about what to do to ensure their safety and protect their property.

1.1 COPING WITH HYDROMETEOROLOGICAL MULTI-HAZARDS

Within the WMO community, scientific advances in weather forecasting have afforded the ability to provide reliable warnings of hydrometeorological multi-hazards at an accuracy and lead time that should directly fulfil the mission of NMHSs: to provide warnings of hydrometeorological hazards in support of safety of life and mitigation of damage to property. In order for governments, economic sectors and the public to take appropriate action, they need to know how hydrometeorological multi-hazards might have an impact on their lives, livelihoods and property and on the economy.

Many people still lose their lives, and socio-economic costs associated with hydrometeorological hazards continue to rise, due, in part, to a lack of appreciation and understanding of the impacts and consequences of hydrometeorological multi-hazards to well-being.

How should WMO Members change what they are doing to solve this problem? And, in doing so, how can they contribute to economic growth by taking advantage of science, technology, data and other resources from within the meteorological community and elsewhere to strengthen the capacity of societies to cope with hydrometeorological multi-hazards?

1.2 DESIRED OUTCOMES

The utility of services and warnings is based on the ability of people to use the information and take effective action. Hence, institutional strengthening and improving observing and forecasting systems and the quality of hydrometeorological warnings are a necessary, but not sufficient, prerequisite to drive down adverse impacts. In summary, an accurate and timely hydrometeorological warning does not guarantee safety of life or prevent major economic disruption (see box on page 2).

National Meteorological and Hydrological Services need to work more effectively with DRCPAs, as well as with the public and stakeholders, to help people understand how hazards can affect them to ensure appropriate actions. By including the vulnerability of infrastructure to hydrometeorological multi-hazards and the likely behaviour of people during an emergency, NMHSs could help minimize the adverse impacts due to fatalities, damage and loss associated with these hazards.

While acknowledging the primary focus on safety of life and property, NMHSs also need to respond to the needs of business for effective services to deliver economic growth and sustainability, growth that depends on exploiting the beneficial impacts of weather and avoiding the adverse impacts.

1.3 IMPACT-BASED FORECASTING

The issues described above could be addressed so as to convey what the impact of a hazard, or multi-hazards, may be to an individual or community at risk. Examples include forecasting the possible impact of rainfall on road users during rush hour, or the impact on passengers of closing

Why do good weather forecasts result in a poor response?

There are numerous examples where the meteorological hazard was well forecast, but the impact was not properly considered and/or was underestimated, and the response inadequate. Two cases illustrate the need to move beyond weather warnings.

Case 1 – Tropical Cyclone *Haiyan (Yolanda)*

The most notable recent example is Tropical Cyclone *Haiyan (Yolanda)*, which struck the Philippines as a category 5 storm on 7 November 2013. As of 14 January 2014, 6 201 people were reported dead, 28 626 injured and 1 785 were still missing; more than 16 million people were affected and the estimate of damage to infrastructure and agriculture was more than US\$ 827 million.* Many of the deaths were caused by the storm surge that resulted from the wind, which reached a maximum 10-minute sustained velocity of 275 kilometres per hour. Would lives have been saved with better knowledge of the specific impacts of this storm? Most likely, yes. Accurate warnings were issued by the meteorological agency – the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) – for heavy rain and winds in time, and the government deployed planes and helicopters to the regions most likely to be affected. However, this was still not enough. Had there been better knowledge of the risks, particularly of the storm surge, it is likely that more extensive evacuations from exposed areas could have taken place sooner.**

Case 2 – Tropical Cyclone *Fitow*

Although much less intense than *Haiyan*, Tropical Cyclone *Fitow* underscores some of the limitations of weather warnings.

Tropical Cyclone *Fitow* began to have an impact on the Chinese mainland on 6 October 2013, causing significant damage and disruption. Between 2000 local time on 7 October and 1400 local time on 8 October, Shanghai received a total of 156 mm of precipitation, the most rainfall in 18 hours recorded since 1961. The impact was very significant: 97 roads were flooded; 900 communities were flooded with many underground parking facilities and cars damaged; and some flood prevention walls were either damaged or destroyed. Overflowing rivers flooded four districts. By 11 October, there were over 1.2 million people directly affected, with one reported death, and nearly 28 million hectares of farmland inundated. The direct economic loss is estimated at RMB 890 million. In the Zhejiang Province, seven deaths were reported and the direct economic loss is estimated at over RMB 33 billion.

The China Meteorological Administration/Shanghai Meteorological Service issued accurate warnings according to standard operating procedures and protocols, increasing the severity from blue to red as the situation worsened. Over 18 million people were alerted.

However, the public response was: "Why were the warnings so late?"

The orange alert for rainfall was issued at 0536 local time on 8 October and the red alert at 0738 local time. This day coincided with the first day of school and work after the Chinese national holiday. The time of issuing the highest alerts coincided with rush hour – the morning commute was well under way before many people became aware of the severity of the situation. Gridlock prevented people from reaching their destinations or returning to their homes.

Why, if the forecast was so accurate, did this happen?

As in most countries, China bases its warning system primarily on meteorological thresholds. Each warning level also includes a summary of recommended actions to be taken when the warning is issued. These actions are usually quite general and do not provide specific guidance for a particular circumstance. The forecaster does not usually consider the vulnerability and exposure of the population to the hazard. In the case of Tropical Cyclone *Fitow*, this meant that the highest level of warning was not issued until well into the morning rush hour when the appropriate meteorological thresholds had already been exceeded.

* National Disaster Risk Reduction and Management Council, 2014.

** WMO, *Post-Typhoon Haiyan (Yolanda) Expert Mission to the Philippines, Manila and Tacloban, 7–12 April 2014, Mission Report* (2014).

an airport due to strong winds. These could be done in a subjective way working alongside transport customers, or in an objective way through developing an impact model using vulnerability and exposure datasets as well as meteorological information. Understanding disaster risk and forecasting hydrometeorological impacts are generally beyond the remit of meteorologists and hydrologists. However, since the risks and impacts are often triggered by extreme hydrometeorological events, it may be argued that NMHSs are best equipped to forecast their impact in partnership with others. In some instances, NMHSs may play a supporting role in providing hydrometeorological information to enable their partners to forecast impacts.

Successful impact-based forecasting requires collaboration with others who have the additional necessary expertise, resources and knowledge (such as demographic data, crowd-sourcing techniques, geographical information systems (GISs), interoperability, and third-party data integration and usage) to deliver impact services that NMHSs cannot do on their own. From the perspective of service users, this would include communities most vulnerable to disasters contributing to the information system. Working closely together, the suppliers of the services and the beneficiaries of those services would provide an integrated, authoritative, unified voice that everyone could resonate with, and in turn could take effective action.

The purpose of these Guidelines is to outline a road map to assist WMO Members to further develop their forecast and warning services in a manner that allows the consequences of extreme weather hazards to be fully understood by users, and appropriate mitigating actions to be undertaken. This road map defines several steps, as outlined herein, to achieve the above purpose. Recognizing that each successive step implies increasing complexity, and requires greater collaboration with relevant partner agencies and the incorporation of data beyond that which is normally used in providing warnings of hazards, special care has been taken in the preparation of these Guidelines to clearly indicate the challenges and requirements involved with each of these successive steps.

These Guidelines are designed to assist WMO Members to progress from weather forecasts and warnings to multi-hazard impact-based forecast and warning services in a manner that is aligned with *The WMO Strategy for Service Delivery and its Implementation Plan* (WMO-No. 1129). They are designed to help NMHSs remain relevant and more responsive to changing societal needs, thus fulfilling their role as the authoritative voice that people want to hear and that they understand, and promoting access to sustainable private sector and donor investment.

CHAPTER 2. KEY CONCEPTS IN IMPACT-BASED AND IMPACT FORECAST AND WARNING SERVICES

Historically, all NMHSs have featured forecasting of the weather as central to their mission. Most also issue weather warnings when hazardous weather is expected. In the case of both weather forecasts and warnings, the focus is on what the weather will **be**. These Guidelines advocate evolving from this weather-based paradigm to one that is focused primarily on forecasting impacts. In other words, the focus should evolve to what the weather will **do**.

Some of the concepts that underpin the idea of impact forecasting go beyond the terms traditionally used in weather forecasting. The critical terms for the purpose of these Guidelines are defined below.

2.1 HAZARD

A hazard is defined as a hydrometeorological-based, geophysical or human-induced element that poses a level of threat to life, property or the environment.

2.2 HYDROMETEOROLOGICAL FORECAST UNCERTAINTY

Hydrometeorological forecast uncertainty refers to the limits of predictability imposed by the state of the science and inherent randomness of the hydrometeorological system. In subsequent sections, these Guidelines will explain more specifically how hydrometeorological forecast uncertainty integrates with factors related to exposure and vulnerability to assist in the quantification of risk.

2.3 EXPOSURE

Exposure refers to who and what may be affected in an area in which hazardous events may occur. If the population and economic resources were not located in (exposed to) potentially dangerous settings, no disaster risk would exist. Exposure is a necessary, but not sufficient, determinant of risk. It is possible to be exposed, but not vulnerable, for example, by living on a floodplain but having sufficient means to modify building structure and behaviour to mitigate potential loss. However, to be vulnerable to a hazard, it is also necessary to be exposed. Exposure is time (t) and space (x) dependent.

An example of exposure related to geographic location would be a vehicle driving across a bridge during a windstorm. To highlight a situational example, a crane would have a much higher exposure during the same windstorm than would a car at street level. Exposure due to timing may exist at various timescales. For example, a windstorm that strikes during the peak of an urban rush hour would result in a much higher exposure factor than if it were to hit an unpopulated rural area in the middle of the night.

2.4 VULNERABILITY

Vulnerability refers to the susceptibility of exposed elements, such as human beings and their livelihoods and property, to suffer adverse effects when affected by a hazard. Vulnerability is related to predisposition, sensitivities, fragilities, weaknesses, deficiencies, or lack of capacities that

favour adverse effects on the exposed elements. Vulnerability is situation specific, interacting with the hazard to generate risk. Therefore, vulnerability may also be time and space dependent.

For example, as flood defences are built they protect the population in low-lying areas. As another example, the State of Florida in the United States implemented stricter building codes following Hurricane *Andrew* in 1992.

2.5 RISK

For the purpose of these Guidelines, risk is defined as the probability and magnitude of harm attendant on human beings, and their livelihoods and assets because of their exposure and vulnerability to a hazard. The magnitude of harm may change due to response actions to either reduce exposure during the course of the event or reduce vulnerability to relevant hazard types in general.

Risk may be mathematically expressed as:

$$| \text{Risk of impact } (x, t) | \\ \equiv | \text{hazard } (x, t) | \cup | \text{vulnerability } (x, t) | \cup | \text{exposure } (x, t) |$$

where \cup is the union of the level of hydrometeorological forecast uncertainty, the degree of vulnerability and the level of exposure. Risks:

- Can be connected to each other and their effects can be compounded. Several or many risks can occur simultaneously within the same area. This requires an ability to compare them and to make trade-offs, assessing the relative importance of one risk in comparison with another, which may not necessarily be hydrometeorological in character;
- Are not always easy to identify, quantify and categorize, and sometimes identification occurs long after serious adverse consequences have been felt;
- Are evaluated differently in social terms. Thus, a risk considered serious in one location may be considered less so in another, or there is flexibility in accepting the risk.

2.6 WEATHER, IMPACT-BASED AND IMPACT FORECASTS AND WARNINGS

These three separate forecasting paradigms are defined for clarity. There is a subtlety in the distinctions amongst them.

Paradigm 1 – Weather forecasts and warnings (hazard only): These types of forecasts and warnings contain information that refers only to atmospheric variables and how they are expected to change. In the case of weather warnings, the focus is on forecasting weather-based hazards only.

Example 1: “Bora winds are expected tonight with wind speeds of 20 metres per second.”

Example 2: “Severe thunderstorms are expected today with wind gusts exceeding 60 mph.”

Paradigm 2 – Impact-based forecasts and warnings (hazard and vulnerability only): These types of forecasts and warnings are designed to express the expected impacts as a result of the expected weather.

Example 1: “Bora winds are expected tonight which may result in delays or cancellation to ferry services.”

Example 2: “Severe thunderstorms with gusts over 60 mph will result in damage to trees and power lines.”

Paradigm 3 – Impact forecasts and warnings (hazard, vulnerability and exposure): These types of forecasts and warnings are designed to provide detailed information down to the individual, activity or community level. For many NMHSs, these types of forecasts will be the purview of partnering agencies rather than the role of the NMHS itself.

Example 1: “Ferry services for the island of Brač will most likely be cancelled tonight due to Bora winds.”

Example 2: “Extensive traffic delays in Kensington may occur due to the risk of large trees downing power lines and blocking roads as a result of severe thunderstorms.”

Important to note is that knowledge of local *exposure* (that is, known ferry routes and neighbourhoods with particularly large trees overhanging power lines) is required in order to formulate impact forecasts.

2.7 SERVICE DELIVERY PARTNERSHIPS: PUBLIC AND GOVERNMENT RESPONSIBILITY

Service delivery partnerships refer to interactions required among NMHSs, DRCPAs and other actors within local, municipal or national governments to implement an impact forecast and warning system. In some countries, NMHSs are empowered to serve in the capacity of describing impacts as well as forecasting the weather. However, in others, DRCPAs retain the authority for impact forecast and warning. In these cases, strong partnerships need to be established so that the full benefits of impact-based forecast and warning services can be realized.

CHAPTER 3. EVOLVING TOWARDS IMPACT FORECASTING

3.1 GENERAL FORECASTS

All NMHSs have, as part of their basic duties, the responsibility to prepare general forecasts for their areas of responsibility. These forecasts are statements of the expected evolution of sensible atmospheric variables such as wind, temperature, humidity and precipitation. Forecasts may be provided in either a deterministic or a probabilistic manner. The change to a more probabilistic approach has grown substantially with the advent of ensemble prediction systems. Communication of forecasts has evolved from forecast provision on a regular schedule (for example, updated four times daily) to a paradigm where forecasts are updated almost continuously, via written text, graphics, radio and – with the advent of wireless technologies – text messages, e-mails and mobile applications.

Example from the Hong Kong Observatory, Hong Kong, China

The Hong Kong Observatory provides weather forecasts to the public, the shipping community, the aviation sector, and other special users through a variety of dissemination channels, including the Observatory's website, mobile application "MyObservatory", the dial-a-weather service, press, radio, television and social networking websites. Television programmes are produced and presented daily by professional meteorologists from the Observatory for broadcast. Radio interviews are also conducted by forecasters and weather service officers from the Observatory on the latest weather situation.

The Hong Kong Observatory also provides automatic weather forecasts based on numerical weather prediction models. The output from computer models is processed and integrated automatically to generate the location-specific forecasts so that the public can better grasp weather changes at the regional level.

3.2 WARNINGS BASED ON FIXED METEOROLOGICAL THRESHOLDS

Many NMHSs have in place warnings to address significant hazards that are expected to threaten life or property. This next level of information includes messages that are provided on a non-routine and an as-needed basis. In general, these products feature provision of specific headline messages, a colour-coded or numbering system, and/or activation of specialized public messaging systems that are only used during extreme events. Hydrometeorological events for which such warnings are provided may include flooding, winter storms, severe convective weather, extreme temperatures and poor air quality.

While messaging within warnings often describes expected impacts to the public and DRCPAs, the driver for issuing these early warnings is often based on weather-based factors only (for example, wind speeds of at least x km/hour, snowfall totalling at least y cm) and can often be expressed as a probability of a fixed threshold being reached or exceeded (for example, there is a 60 per cent probability of winds speeds of at least x km/hour being reached).

Example from the United States National Weather Service	
The National Weather Service utilizes the Saffir–Simpson scale (http://www.nhc.noaa.gov/sshws.shtml) to categorize and convey the impacts of tropical systems based on increasing wind speed.	
Category	Sustained winds
1	74–95 mph 64–82 kt 119–153 km/h
2	96–110 mph 83–95 kt 154–177 km/h
3 (major)	111–129 mph 96–112 kt 178–208 km/h
4 (major)	130–156 mph 113–136 kt 209–251 km/h
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher

3.3 WEATHER WARNINGS USING RELEVANT THRESHOLDS AGREED WITH USERS/PRACTITIONERS

Some NMHSs are now working with other non-weather-related organizations, such as business, security and finance industries, and health and safety organizations, to quantify thresholds and provide targeted warnings based on them. Such thresholds are often developed based on a probability of occurrence for a given hazard, and thereby assist organizations in decision-making and the management of their activities. An example of this is the development of criteria to support warnings for an aerodrome, with preset thresholds being agreed with the customer.

3.4 WEATHER WARNINGS WITH SPATIAL/TEMPORAL VARIATION IN THRESHOLDS

At this stage in the evolution towards impact-based warnings, the thresholds are no longer predefined and may vary according to the situation in space and time, to represent changing vulnerabilities.

Example from Météo-France

Heatwave thresholds were built in cooperation with the French Institute for Public Health Surveillance (InVS) of the Ministry of Social Affairs, Health and Women's Rights.

For this specific hazard, mortality surveys were conducted and matched with climatological data, and led to the design of a biometeorological index, based on a combination of extreme temperatures. Thresholds were then determined according to the results of the surveys and adapted throughout the country, with results varying significantly between the north-western part of the country and the Mediterranean areas in the south-east, for example.

Temporal variation in thresholds – example of the United States Flash Flood Guidance System

As its name suggests, this is a service that has been designed to provide “the near-term risk of a flash flood in small streams and basins”. It has been developed by the Hydrologic Research Center in San Diego, California.

The aim of the Flash Flood Guidance System is to provide a diagnostic value (known as flash flood guidance) that estimates the amount of rainfall over a given duration within a basin that is required in order to cause flooding within the catchment. The System is designed to update its values and to “remember” rainfall that has already entered the catchment. In this way, the System takes account of antecedent catchment conditions and can calculate the amount of extra rainfall that is needed in order to produce flooding. When these values are applied in real time with nowcasts or in a forecasting capacity, they can be used to generate a flash flood warning.




The System has been used for many years by the United States National Weather Service and is a good example of a weather warning that is driven by non-fixed, variable rainfall thresholds.

Example of spatial variation in thresholds from the Meteorological and Hydrological Service of Croatia

Temperature thresholds for the heatwave hazard for eight towns in Croatia

Minimum temperature (°C)				Maximum temperature (°C)			
Osijek	20.1	21.2	22.9	Osijek	35.2	36.7	38.8
Zagreb	20.2	21.3	22.9	Zagreb	33.7	35.1	37.1
Karlovac	20.0	21.1	22.7	Karlovac	34.5	35.9	38.0
Gospić	17.0	18.0	19.6	Gospić	32.1	33.4	35.4
Rijeka	22.7	23.7	25.1	Rijeka	32.7	33.9	35.5
Knin	20.5	21.6	23.1	Knin	35.5	36.9	39.0
Split	25.8	26.8	28.2	Split	33.9	35.1	36.7
Dubrovnik	25.4	26.3	27.6	Dubrovnik	32.3	33.2	34.7

Description of thresholds

	Moderate heatwave hazard
	High heatwave hazard
	Extreme high heatwave hazard

3.5 MULTI-HAZARD IMPACT-BASED FORECAST AND WARNING SERVICES

As the next step in the evolutionary process towards impact forecast and warning services, it is recommended that all NMHSs consider the potential benefits of providing impact-based warnings to the public and to DRCPAs. The fundamental distinction between a general weather warning and an impact-based warning is the inclusion of vulnerability of people, livelihood and property with consideration of the hydrometeorological hazard. That is, the impact of the weather drives the messaging, rather than the weather itself.

Migrating to an impact-based paradigm involves a number of complex factors. For example, a forecast showing a value exceeding a certain combination of temperature and relative humidity may trigger a heat warning. However, in an impact-based warning framework, the issuance of a heat warning is driven not only by the hazards themselves, but also by their locations and timing. In some cases, NMHSs may wish to offer a different hazard message for an excessive heat event that occurs very early in the season than it would for an identical event during mid-summer, or a forecast for a flooding event that may have much more impact in a highly populated area than in a rural environment (vulnerability factor).

Vulnerability may change with respect to the hazard and will be modulated by the integrity of infrastructure, as well as exposure or sensitivity of populations. Vulnerability itself may change with time as the integrity of infrastructure is bolstered. One example of the latter factor was the implementation of stricter building codes in Florida following Hurricane *Andrew* in 1992.

Vulnerability assessments, often conducted to develop risk transfer mechanisms such as insurance, may provide the ideal source of data on the vulnerability of physical infrastructure. One example of this is the Pacific Catastrophe Risk Assessment and Financing Initiative, which has systematically collected data at the household level throughout many Pacific island countries.

Example from China

An example of an impact-based typhoon warning follows: On 10 August 2013, the violent Typhoon *Jutte* developed over the east ocean of the Philippines. On 11 August, *Jutte* had reached super typhoon strength and made landfall in Guangzhou on 14 August. The Meteorological Administration of Guangdong Province had paid a great deal of attention to *Jutte*, especially from 11 August. As part of its service, the Meteorological Administration forecast the landfall, precipitation and wind speed distribution of *Jutte* using the typhoon model. Using this information, the Administration was able to draw a map of impacts using the typhoon disaster impact assessment model. This model divides impacts into seven grades using a colour-coded model. For example, red means serious impact and green means slight impact. These impact maps were offered to the DRCPAs, the transportation department and other provincial government departments. These departments arranged the disaster prevention and reduction work according to the impact maps.

3.6 IMPACT FORECAST AND WARNING SERVICES

For impact forecast and warning services, exposure is explicitly considered along with the hazard and vulnerability. These types of forecasts and warnings are designed to provide detailed information precisely on who or what is exposed.

In order to provide these types of warnings, NMHSs (or the responsible government agency) must have available detailed vulnerability and exposure information relevant to the hazard and individual entities for whom (or which) the forecasts are provided. Impact forecast and warning services can only be provided in instances where an NMHS has developed strong partnerships with other relevant agencies or with user communities.

Critical to a successful warning service, as mentioned earlier, is the development of strong relationships between NMHSs and DRCPAs so that these warnings can be as relevant and useful

as possible. In fact, it could be argued, especially given the increasing reliability of numerical weather prediction and the proliferation of digital forecast databases driven by numerical weather prediction models, that an increasing proportion of the forecasters' time will need to be dedicated to such collaboration and relationship development.

Thus, NMHSs will need to dedicate resources towards understanding the relationships between the spatial and temporal variations in vulnerability and exposure as they relate to various hazards. This understanding would thereafter be translated into NMHS warning messages that provide meaningful impact information for those they serve.

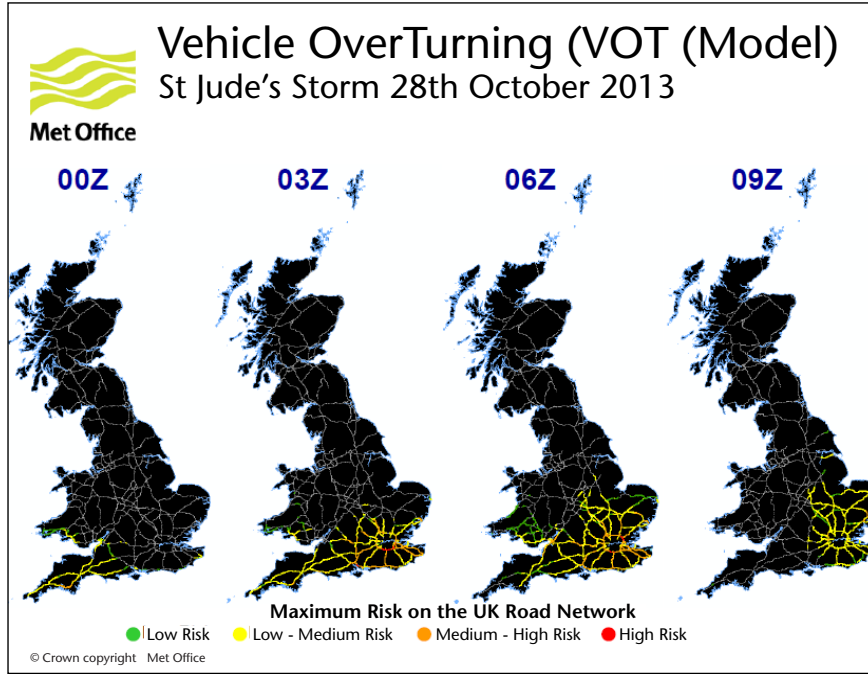
Having defined above the evolution from general weather forecasts to impact warnings, the table below reviews how worded warnings may evolve using a heavy rain event as an example.

<i>Evolving warning paradigm using a heavy rain event as an example</i>		<i>Factors incorporated</i>
General forecast	A cold, windy, wet day tomorrow with spells of very heavy rain expected in the afternoon and evening.	Hazard
Warnings with fixed thresholds	Rainfall accumulations of 30 mm to 40 mm expected tomorrow between 1400 and midnight.	Hazard
Warnings with user-defined thresholds	Heavy rain expected tomorrow afternoon with rainfall intensities of 3 mm/10 mins possible, leading to overflow in the drainage system. <i>(Note that this type of warning would typically be issued to a municipal authority only.)</i>	Hazard Vulnerability
Warnings with spatial and/or temporal variations in thresholds	Spatial differences: Weather warning – rainfall accumulations of 20 mm to 30 mm expected tomorrow in low-lying areas between 1400 and midnight, with accumulations of 50 mm to 60 mm possible at altitudes above 1 500 m. Temporal differences: Weather warning – rainfall accumulations of 15 mm to 20 mm expected tomorrow afternoon during rush hour. <i>(Note the lower threshold at times when the roads will be very busy.)</i>	Hazard Vulnerability
Impact-based warning	Rainfall accumulations of 20 mm to 30 mm expected tomorrow between 1400 and midnight, resulting in possible road closures due to flooding across the south-east. <i>(Note the subtle but important distinction between the impact-based warning and the threshold warning described above. The distinction is that the threshold-based warnings only specified generalized flooding; the impact-based warning provided specific mention of an impact, in this case road closures.)</i>	Hazard Vulnerability
Impact warning	Expect journey times on the A111 likely to be lengthened by an hour because of significant traffic disruption in the south-east tomorrow afternoon due to localized flooding which is expected to follow a heavy rain event.	Hazard Vulnerability Exposure

Example from the United Kingdom (the Met Office)

Forecast of a direct impact – in this case the risk of overturning vehicles due to high winds.

It is important to note that the highest impacts (in red) were not at the locations of the expected highest winds.



Example from Environment Canada

Environment Canada has implemented an impact approach to its air quality programme (http://weather.gc.ca/airquality/pages/index_e.html). Through partnerships with federal, provincial and municipal environment and health authorities, forecasts and warnings of the Air Quality Health Index are based on identified levels of risks to health and associated potential impacts on people at risk. Call to action statements, to reduce the risk associated with the forecasted air pollution levels, are included in these products.

Air Quality Health Index

Choose a Provincial Summary
 AB | BC | MB | NB | NL | NS | ON | PE | QC | SK

This table shows a summary of the most recent forecast values of the Air Quality Health Index for many Canadian cities.

City	Value
Calgary	3 - Low Risk
Charlottetown	2 - Low Risk
Edmonton	3 - Low Risk
Fredericton	2 - Low Risk
Halifax	3 - Low Risk
Montréal	3 - Low Risk
Ottawa (Kanata - Orléans)	4 - Moderate Risk
Prince George	2 - Low Risk
Quebec	3 - Low Risk
Regina	4 - Moderate Risk
Saint John	2 - Low Risk
Saskatoon	4 - Moderate Risk
St. John's	2 - Low Risk
Toronto	3 - Low Risk
Vancouver	3 - Low Risk
Winnipeg	3 - Low Risk

Toronto – Air Quality Health Index

Current Past 24 hr | AQHI by Station

Observed at: 1:00 PM EDT Thursday 18 April 2013

3

At-Risk Population:
 • Enjoy your usual outdoor activities.
 • Find out if you are at risk.

General Population:
 • Ideal air quality for outdoor activities.

Forecast Maximums Health Message

Issued at: 6:00 AM EDT Thursday 18 April 2013

Thursday	4 - Moderate Risk
Thursday night	4 - Moderate Risk
Friday	3 - Low Risk

Who is at risk?
 People with heart and lung conditions are most affected by air pollution.
 To find out if you are at risk, consult the [health guide](#), your physician, or your [local health authority](#).
 Visit the [national AQHI Web site](#) to learn more about the AQHI.

Did you know...?
 To reduce air pollution, you should limit the use of small gas-powered machines such as lawnmowers, leaf blowers, chainsaws and snow blowers.

The AQHI is an initiative between Environment Canada, Health Canada, The Ontario Ministry of the Environment, The Ontario Ministry of Health and Long-Term Care, Toronto Public Health and the Clean Air Partnership.

3.7 SCHEMATICS DEPICTING CONCEPTUAL AND OPERATIONAL APPLICATIONS OF IMPACT FORECASTING

Before moving towards impact-based or impact forecasting, it is important that an NMHS understand the possible conceptual models that underlie the paradigm, as well as the operational approaches currently in use.

Conceptual paradigm

Figure 1 represents the relationship among the key elements of an impact forecast system. There are three possible pathways towards estimating an assessment of impact for a given hydrometeorological hazard:

1. The solid orange arrows represent the modelling approach where each element is explicitly calculated. To do this requires detailed data on vulnerability and exposure, which may need to be acquired from other agencies.
2. The dotted orange arrow relates a more subjective approach where qualitative information is collected from expert partners. This information represents the sum of their experience and allows the estimation of impact directly from the magnitude of the hazard.
3. The red arrows represent a more traditional approach whereby the magnitude of the likely impact is related directly to the magnitude of the meteorological hazard. This approach can help in identifying and reducing risk, but takes no explicit account of exposure or vulnerability, only the magnitude of the meteorological hazard itself.

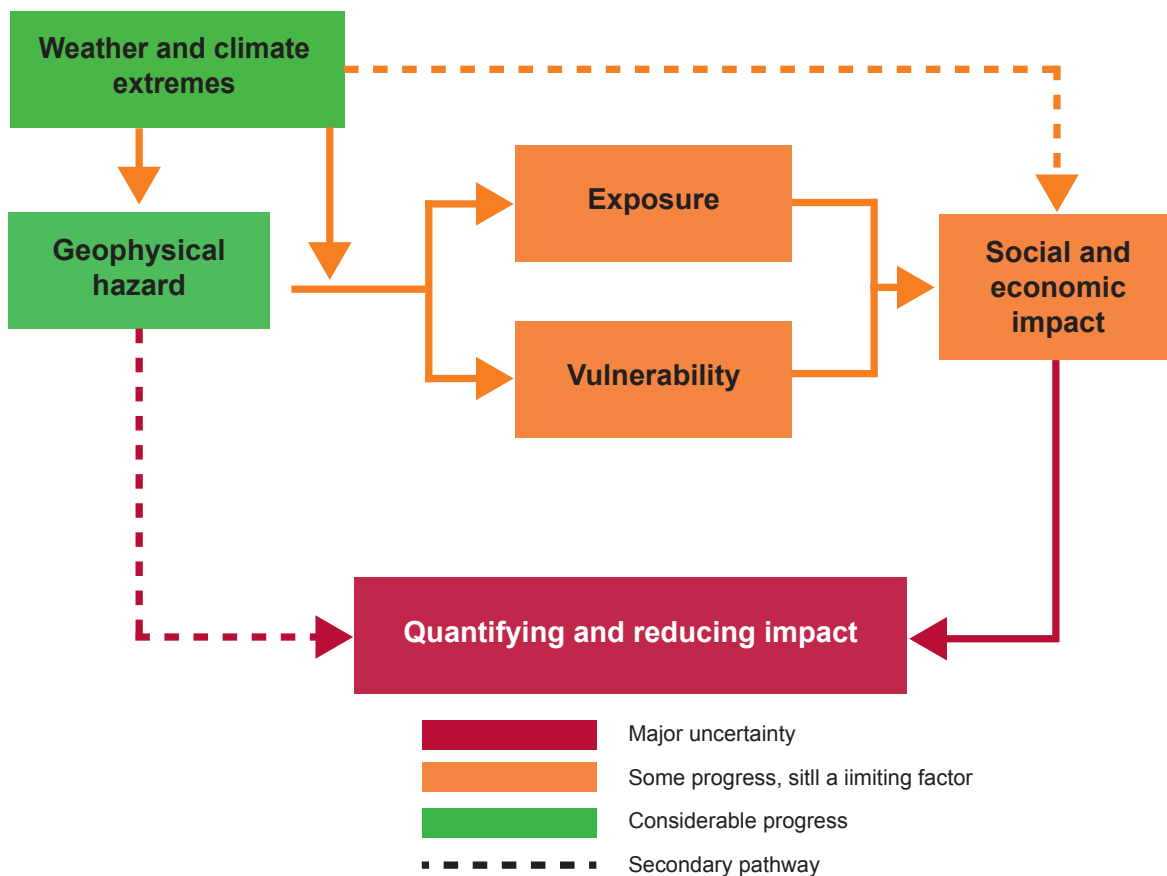


Figure 1. Relationship among the key elements of an impact forecast system

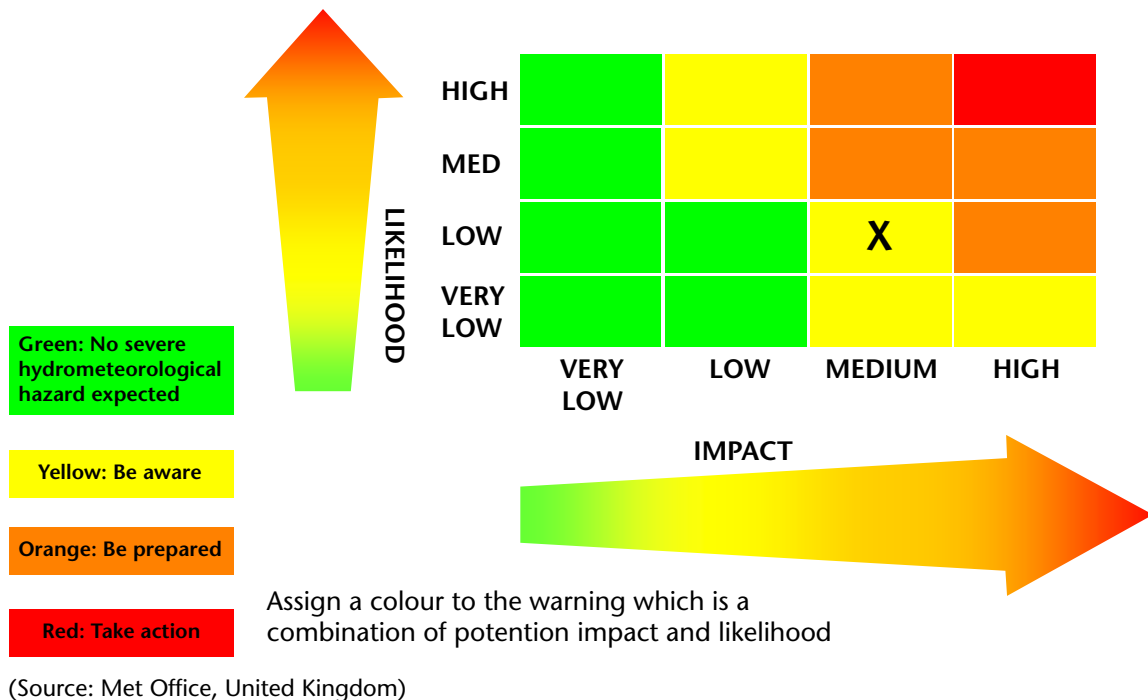


Figure 2. Risk matrix

Operational approach

It is recommended that NMHSs work with their DRCPAs to identify how the likelihood of an expected hazard and its potential severity can be considered in tandem to create a risk matrix. Figure 2 illustrates a suggested operational application of the impact warning concept, combining impact with likelihood to create a risk matrix, expressing risk through a simple “traffic-light” colour scheme. It is to be recalled here that impact incorporates an assessment of vulnerability and exposure.

In contrast to the traditional threshold-based or “yes/no” weather warning system, the approach exemplified by the matrix in Figure 2 facilitates the following:

1. A consistent means for the early expression of potential impact, well in advance of a significant hydrometeorological event.
2. A means to progressively express changing expectations of risk as a function of varying exposure, vulnerability and hydrometeorological likelihood.

This approach is used by the Met Office of the United Kingdom and a number of other European NMHSs that contribute to the Meteoalarm system (www.meteoalarm.eu).

3.8 BENEFITS OF AN IMPACT WARNING SERVICE

The creation of impact warnings and the systems supporting them are based on close coordination between NMHSs and different organizations, including DRCPAs. The benefits of these partnerships are multiple and ensure that the sharing of knowledge and expertise render the impact messaging relevant to the users of this information. Specifically, the process of developing an impact framework results in the following:

- Improved planning for different scenarios based on different thresholds, impacts or combinations of impacts occurring;
- Better contingency planning (best, reasonable worst-case and most likely outcomes);
- Information about level of confidence in the forecast that would convey additional information for better decision-making (a more informed risk assessment);
- New information to facilitate wider social benefits;
- The basis for post-event analysis of natural multi-hazard impacts to assist in planning, response and mitigation of impacts;
- A comprehensive and coordinated process to address disaster response and preparedness;
- Common situational awareness.

Impact forecasts and warnings relay a message of greater relevance to enable those at risk to take appropriate actions in order to mitigate the overall adverse effects of hydrometeorological hazards.

CHAPTER 4. RECOMMENDED ELEMENTS IN THE DEVELOPMENT OF IMPACT FORECAST AND WARNING SERVICES

In order to realize the benefits of impact forecast and warning services, as described in Chapter 3, NMHSs will need to address the development of systems and of their staff in partnerships with many other agencies. The following describes some of these elements.

4.1 PARTNERSHIPS

National Meteorological and Hydrological Services have the expertise and capacity to deal with hydrometeorological forecasting and warnings. However, in the course of their normal work, meteorologists will not normally learn about vulnerabilities, exposure and emergency disaster management. Therefore, collaboration with and support from their governments, international bodies, scientific institutions and local communities are needed. This should result in better risk assessments, improved monitoring, early warning and enhanced overall response to hazards and disasters.

Key partnerships need to be established with those organizations that have direct responsibility for the safety and security of populations. Among these, DRCPAs are key partners and users. They can help evaluate vulnerabilities, potential impacts and mitigation actions necessary to counter impacts. Depending on national public policies, these agencies could be in the position to lead the impact-based warnings development process, even if these are initiated and supported by the NMHS.

The *Guidelines for Creating a Memorandum of Understanding and a Standard Operating Procedure between a National Meteorological or Hydrometeorological Service and a Partner Agency* (WMO-No. 1099, PWS-26) provides examples that identify certain key steps in developing these partnerships and agreements. To enable the sharing of data, good practices and support among NMHSs and relevant partners, a common and collective understanding of the decision-making processes involved in disaster reduction, from the first warning of the event to the response and recovery, must be established.

In developing partnerships with potential agencies, the following should be considered:

- Determine those government entities and other stakeholders that should support, or already support, the need for impact forecasting;
- Define clear governance between parties including steering committees and advisory groups;
- Ensure that an agreed legal framework is put into place to facilitate intellectual property sharing and exchange of good practice;
- Establish programme management to include roles and responsibilities for development, implementation, delivery and verification of impact-based products and services;
- Develop a communications strategy to define expected services, the respective role(s) of parties (including local populations), and outreach activities;
- Agree upon a strategy to verify, evaluate and provide a quality management system and assurance of products and services;
- Assess whether international cooperation is required.



Figure 3. United Kingdom Natural Hazards Partnership

In 2011, the Natural Hazards Partnership (NHP) was created in the United Kingdom to improve the coherence and quality of hazard management across government, and the planning, preparation, warning and response to natural hazards. The NHP is a partnership of key United Kingdom organizations that play a leading role in natural hazard science and research (see Figure 3).

The vision of the NHP is to deliver coordinated assessments, research and advice on natural hazards for governments and resilience communities across the United Kingdom.

4.2 DEVELOPMENT OF INFORMATION AND SERVICES

Once NMHSs have established partnerships, the next step is to leverage these relationships to jointly design and develop an impact-focused framework. This links historical hydrometeorological events with information about vulnerability, exposure and recorded impacts. It is recommended that the NMHSs' contribution rely upon historical data and climate data available in their climate services units. The resulting impact-based criteria should be shared and made readily accessible by all parties.

These criteria will be determined from a variety of factors including hazard, vulnerability and exposure information based on specific weather criteria, risk assessments and maps, and socio-economic data. Also required is a means to monitor and react to changing situations via a number of sources, potentially including social media, to ensure that up-to-date warning information reaches all users.

A holistic approach to observing, modelling and predicting severe weather and the consequent natural hazards, through to their impacts, needs to be developed. This will require a multidisciplinary, highly integrated and directed scientific endeavour to translate natural hazard risk into impact services, and a validation process to assess service benefits and performance bespoke to users. Observing strategies may need to be revisited so that they can capture, exchange and integrate impact observations into forecasting systems. This will bring twofold benefits: first, to validate impacts and their consequences (this might be achieved through crowd-sourcing technologies); and, secondly, to provide the initial conditions that are needed to drive downstream impact models. The list of observations could be far-reaching and diverse, involving social media, unconventional observations captured from mobiles and other technologies (for example, transport) and webcams, and so forth.

This aspect will require further consideration, because to genuinely share impact observations requires an ability to integrate, categorize and manage third-party observations in a manner not done thus far; establishing agreed data formats and data standards; developing the principles through which data can be exchanged and shared; crafting systems that can work together; and reaching joint agreements to management foreground¹ and background² intellectual property rights.

Services will then be developed to meet user requirements, keeping in mind that the ultimate purpose is to reduce the adverse impacts of hydrometeorological events. As a consequence, requirements such as timeliness, clarity of message, and update schedules will be as important as the scientific or technical requirements with which meteorologists are more familiar.

4.3 **FUNCTIONAL REQUIREMENTS FOR IMPACT-BASED FORECASTING AND WARNINGS**

This section introduces technical and functional features required in the development of the collaborative system supporting forecasts and warnings that focus on impacts.

Technical features to be considered are:

- Data and metadata management including acquisition, harmonization, interoperability and sharing strategies;
- Implementation of relevant technical tools (databases, models, information);
- Dissemination platforms, protocols and formats such as XML/CAP, colour-coded graphics and GIS layers;
- Continuity of operations;
- Archiving.

¹ The new intellectual property that is developed through a relationship between two agencies collaborating together.

² The intellectual property developed independently by each individual agency prior to entering into the collaboration relationship.

Operating features within and between cooperating agencies should be established to specify:

- Operational workflow between partners;
- Dissemination processes, communication and interaction with media;
- Backup means and contingency procedures;
- Real-time monitoring of impacts and feedback;
- Crisis management arrangements (escalation process, crisis communication);
- Post-event assessment.

4.4 **DEVELOPING THE CAPACITY OF NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES STAFF AND PARTNERS**

As has been identified in the previous sections, the development of impact-based and impact forecasting entails the gathering of requirements, the establishment of infrastructure, technical development, operating and communication processes, and the identification of roles and responsibilities of all partners involved. Although a significant amount of effort and work will be required to address these aspects, success in the development and later implementation of this initiative will be based primarily on the human resources within organizations. The evolution towards impact-based and impact forecasting will require a change in culture for many NMHSs as well as developments in the relationships they have with existing partners.

In order that their staff address and adopt this new endeavour, organizations must ensure that they provide the means to develop the required set of skills and competencies, as well as the knowledge of how partners mutually use information to deliver on their mandates. Understanding hydrometeorological concepts is part of the picture. However understanding how these are integrated within partners' decision-making is essential. The following need to be considered:

1. Identifying required competencies and skills

Once roles and responsibilities are established within organizations, a professional competency framework must be determined with respect to both functional and behaviour competencies, such as communication (see the *Abridged Final Report with Resolutions and Recommendations of the Extraordinary Session (2014) of the Commission for Basic Systems* (WMO-No. 1140), Recommendation 1 (CBS-Ext.(2014) – Competency Framework for Public Weather Services Forecasters and Advisers).

2. Cross-training on specific requirements and procedures

Staff of NMHSs and of partners should have an understanding of common features of the system, and of the potential limits of tools and interpretation in order to adequately interpret information and data that will be exchanged. Simulation exercises and collaborative workshops are recommended to achieve this training.

3. Educating users on how to use impact forecast information

The media, the public and specific users must be informed as to how warning information produced can be best used to mitigate impacts.

4.5 **VALIDATION**

Validation is viewed here in the usual quality management perspective with the aim of bringing evidence of what is working well and what requires improvement within a system.

This is not only a matter of objective verification and computation of scores that NMHSs customarily produce (for example, verification of numerical weather prediction), but assessing the total performance of an impact-based or impact forecast and warning system.

The validation process should be organized and agreed upon during the partnership-building phase, as it is crucial that such assessment address the overall system and be performed in a collaborative manner.

Success of an impact-based or impact forecast validation process will depend upon the capacity of NMHSs and partners to gather, store and share as much information as possible on the actual impacts of a hydrometeorological event, in addition to simulation exercises that help validate procedures.

It is strongly recommended that:

- Impact-based monitoring tools, capabilities and networks to verify impact-based forecasts and warnings be developed;
 - Evaluation be performed systematically for significant events (to be defined and agreed upon; see section 4.1 above);
 - All those involved during the event participate in evaluation of their contribution and in the feedback process with respect to achieving their mandate;
 - Regular meetings be held with stakeholders to establish a comprehensive analysis of the events from warning to actions taken, and consequences from the user/stakeholder point of view;
 - Improvement be planned, trialled and operationalized according to evaluations and feedback by the users;
 - Success stories be used as good practice examples and proof of concept among partners, stakeholders and with the public.
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CHAPTER 5. OVERARCHING MANAGEMENT APPROACH FOR EVOLVING TOWARDS IMPACT-BASED AND IMPACT FORECAST AND WARNING SERVICES

Implementing impact-based and impact forecast and warning services requires significant behavioural changes of staff within NMHSs and their partners. One recommended approach is to adopt a change management framework policy that enables a smooth transition from weather forecasting to impact forecasting. This chapter provides a systematic approach for how such a framework could be applied, based on a five-step approach: awareness, desire, knowledge, ability and reinforcement, the so-called ADKAR model.³

A change management model applied to impact forecasting

Stage 1. Awareness: secure consent

- Initiate discussion to raise awareness of the issues and need for impact-based and/or impact forecast and warning services within NMHS and between NMHS and DRCPAs or equivalent government department (see section 4.1 above);
- Extend consultations among stakeholders, including government agencies and academia;
- Coordinate with these agencies to raise the relevance of impact-based and impact forecast and warning services, and their benefits;
- Agree initial communications and messaging for internal and external use;
- Forge consensus and support the need to proceed to the next step (Stage 2).

Stage 2. Desire: endorsement and assessment

- Bring together partners and experts, through a workshop, preferably hosted at a neutral site:
 - To introduce the benefits of impact-based and impact forecasting;
 - To analyse and review the issues and gaps;
 - To find out what each partner wants, or does not want, from the partnership;
 - To reach a common ground on the proposed level of impact forecasting required from simpler multi-hazard impact-based forecasts and warnings (see section 3.5 above) to user-specific, tailored impact forecasts and warnings (see section 3.6 above);
 - To develop a strength, weakness, opportunities, threats (SWOT) analysis to identify the capacity and capabilities of each partner, for example, the capacity to respond to warnings by DRCPAs.
- Explore, prioritize and rate those hazards and impacts that are of importance in the particular country or region;

³ Jeffrey M. Hiatt, *ADKAR: A Model for Change in Business, Government and Our Community* (Loveland, CO, United States, Prosci Inc., 2006).

- Determine the current status of vulnerability assessments to the prioritized meteorological hazards; identify gaps in knowledge; and develop a plan to address these gaps;
- Develop hazard-specific, time-dependent exposure information for human activities;
- Innovate, using the science-to-service ethos, to identify new, to enhance, or to retire existing impact-based and impact services.

Stage 3. Knowledge: planning and integration

- Develop a memorandum of understanding (see section 4.1 above);
- Introduce project management and control:
 - To develop an operating plan with an agreed vision, mission, objectives, milestones, funding model and financing trials, benefits realization plan, risk register, etc.;
 - To create a legal framework for intellectual property and data exchange/usage, etc.;
 - To collect, manage, categorize, store and exploit data;
 - To establish working groups, chairpersons and associated terms of reference;
 - To build trials to develop new services, or to enhance or retire existing ones;
 - To ensure minute taking and recording;
 - To communicate and engage with stakeholders;
- Set up institutional framework, as required;
- Train providers and users of services based around a competencies framework;
- Formulate monitoring and evaluation tools to assess service progress and improvements.

Stage 4. Ability: apply and implement

- Implement the impact-based and/or impact forecast and warning services;
- Monitor implementation and communicate with users;
- Prepare regular updates between partners and users;
 - Newsletters/newsgroup/website/meetings;
- Create a user group of customers and establish terms of agreement;
 - Establish feedback protocols and quality assurance with the user group so that during trials the partnership can evaluate and verify the usefulness and relevance of new services;
- Create a core group of stakeholders and funding partners to challenge, support and assist in building and implementing a sustainable business/funding model;
- Develop a branding and marketing strategy (attribution to partners);

- Conduct post-event evaluation and promote benefits of impact-based forecasting;
- Continue to refine protocols and services;
- Challenge science to develop impact, risk and social science research;
- Challenge technology to deliver application layers, for example, GIS tools, to mash data and delivery channels to disseminate information;
- Develop impact-based monitoring capabilities and databases to capture impact information.

Stage 5. Reinforcement

- Operationalize and implement those services trialled that were cost-effective and delivered the most value to customers;
 - Operate a quality management system;
 - Enhance partner and user coordination;
 - Sustain resources and funding to enhance services;
 - Provide continuous training and mentoring;
 - Focus on continuous improvement;
 - Consider expanding partnerships.
-

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